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PHYSIOLOGICAL INERTIA AND PHYSIOLOGICAL MOMENTUM

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NEWTON'S first law of motion states: "Every body continues in its state of rest or of uniform motion in a straight line, except in so far as it is compelled by forces to change that state."

The conception of inertia is inherent in this famous definition, for that property of matter in virtue of which matter tends to maintain its state of rest or of uniform motion in a straight line, is called inertia.

Functional inertia is that property of living matter (bioplasm) in virtue of which, having received a stimulus, it continues to maintain the functional status quo ante, whether that was activity or inactivity; and functional momentum is that property of bioplasm in virtue of which the living matter, having responded to a stimulus, continues to exhibit its activity or inactivity after the stimulus has ceased to exist. Functional or physiological inertia is that property of living matter which maintains the status quo ante, namely, non-response to a stimulus tending to arouse a response (functional inertia of rest), or response after the stimulus has ceased (functional momentum).

Affectability is that property of living matter in virtue of which it responds to a stimulus either by activity or by the quelling of activity (inhibition). States of inactivity or inhibitions are, therefore, equally with activity responses to stimulation. We may express the inter-relations of these factors as follows:

A stimulus having been received, then if affectability predominates there may be either activity or inactivity; and conversely, if functional inertia is predominant when the stimulus is received, there will be activity, if activity was the status quo, but inactivity, if inactivity was the status quo. Finally, the stimulus having ceased to act, there will be, owing to functional momentum, activity, if activity was the status quo, inacivity if inactivity was the status quo. As a recent writer in *Nature* puts it—"Responses to stimuli cannot take place instantly, neither do stimulation effects fade away momentarily."[1]

Some definite examples might be given: a stimulus is applied to a muscle at rest; the muscle does not shorten until after a "latent period" which is lengthened by cold and fatigue: here the functional inertia of the muscle maintains the status quo ante of inaction: the heart is beating when a stimulus tending to stop it (inhibit) is received, the heart makes a beat or two before it stops; here the status quo ante of activity was maintained.

If the cardio-accelerator nerves of the heart are stimulated, the heart's action is accelerated, on stopping the stimulus the heart continues to beat fast for some time before it resumes its pre-stimulant rate; this is post-stimulant activity due to physiological momentum. If the vagus or inhibitory nerve of the heart is stimulated, the heart can be brought to a standstill; when the stimulus is withdrawn, the heart remains quiescent for some time before it resumes beating; this post-stimulant inhibition is due to functional momentum.

Both properties, affectability and functional inertia, coexist in bioplasm, at one time one predominates, at another another. Thus, in the heart cycle during systole, functional inertia predominates, for a stimulus given during systole is totally disregarded (refractory period). During diastole, affectability predominates, and a stimulus given during that phase elicits a small systole (extra systole). This functional inertia during systole makes it impossible to tetanize the heart.

These limits set to metabolic possibilities are due to the possession of functional inertia, a property possessed contemporaneously with affectability. Thus, as I wrote in 1908, the manifestation of life at any given instant is to be regarded as the resultant of two coexisting but physiologically opposite functional propensities or capabilities; the degree of whose relative intensities conditions the character of the particular manifestation at the moment; response if affectability be the predominating condition; non-response if functional inertia be the characteristic state. Non-correspondence with environment is the keynote of protoplasmic inertia; independence of environment, disregard of stimulation, inaccessibility to external influences, insusceptibilities, resistances, limits to powers of response—a holding on the even tenor of the metabolic way.

Limits to rates of activity, superior limits to rhythms, are inertial. Cilia bend to and fro at about ten to twelve a second at ordinary temperatures; but on being heated can not do so faster than twenty a second. Thus the (rabbit's) heart heated can not perform systoles at a greater rate than six a second, our respiratory center can not discharge impulses at a greater rate than about two per second, we can not perform twitching movements of the fingers at a greater rate than about twelve a second, nor articulate more than about ten to twelve syllables per second, and so forth. Professor Sir A. Schäfer, Professor Waller, Professor Starling, Sir S. Sharkey and the late Professor Mosso, all use the term "inertia" as referring to nerve cells.

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[1] *Nature*, January 3, 1919, p. 354.

Closely allied to inertial limits are inherent rhythms, as demonstrating a disregard of environmental stimuli. For instance, the "post-tetanic tremor" (D. F. H.) in which a muscle twitches at about four to six a second, although it is receiving stimuli at a rate which, when it was unfatigued, produced in it complete tetanus.

Protoplasmic inertia is the physiological counterpart of affectability. Dead organisms have no affectability at all, but infinitely great functional inertia. Those in latent life (Scheintod) have very little affectability and much functional inertia. Thus the dried Rotifera, Tardigrada and many ova amongst animals; and seeds, resting (winter) buds and frozen bacteria, etc., amongst plants, are all cases of insusceptibility due to the possession of a high degree of functional inertia. Seeds, for instance, have little affectability; they will give an electric response to a powerful condenser discharge sent through them, but otherwise their inertia is extreme. As a French writer puts it, they are "tombés dans un état d'inertie complète." Writers in clinical medicine clearly recognize the condition which I am describing as a fundamental property of protoplasm. Thus Dr. R. W. Leftwich[2] writes of a type of coughing that "persists for long after the condition which produced it has passed off."

My early critics misapprehended my position in one or two respects; some complained, for instance, that functional inertia explained "too much." They might as well have complained that affectability explains too much. They failed to recognize that both these fundamental, vital properties—affectability and functional inertia—are coexistent and omnipresent, that there is no portion of living matter that does not possess some of each property, and that, therefore, between them they must "explain" the whole of life. Of course no property of protoplasm "explains" life; but all manifestations of livingness are dependent on the simultaneous possession by living matter of two complementary and equally fundamental properties, affectability and functional inertia. At no time in the life of the organism is there absolutely only one of these properties in existence; in death functional inertia is maximal and affectability has disappeared. The converse of this, a state of infinite affectability with no functional inertia, is not known now and here on this globe.

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[2] "Aids to Rational Therapeutics," R. W. Leftwich, M.D., London, Bailliere, Tyndale, Cox, 1918, p. 6.

Physiological insusceptibility may be absolute, as in such cases as light waves falling on the auditory nerve or sound waves on the optic where there are no responses whatever. These and similar conditions might be called absolute functional inertia; but inasmuch as the stimuli are not only heterologous but perfectly inappropriate, these cases need not further detain us. The case, however, of the stigma of a particular species of plant being insusceptible of fertilization by the pollen of some other species is another case of the same sort of inertia.

Certain idiosyncrasies may be related to the two properties of protoplasm thus—extreme "susceptibility" towards a poison or drug is due to extreme affectability towards it, whereas a high degree of resistance to a poison or drug is the outcome of a relative functional inertia towards it.

A tissue performing some chemical transformation may exhibit functional inertia under one of its many aspects; the tissue or organ may exhibit a longer or shorter latent period after the exciting stimulus has been received; it may maintain its own particular rate or pace of activity; it may produce its own proper chemical transformations after the stimulus has ceased to exist; and, finally, it may be concerned in such an activity as the excretion of uric acid, which is in itself regarded by some physiologists as chemically a vestigial process. On this view, the excretion of uric acid by the mammal is a survival of a chemical activity characteristic of an avian ancestor. The excretion of this acid is thus an example of the maintenance of a chemical status quo ante.

Physiological momentum is strikingly shown by certain vegetable organisms. The opening and closing of certain flowers goes on for some days after the plants have been placed in the dark; "the seasonal periodicity is exhibited by deciduous trees when removed to countries where the vegetation is evergreen."[3]

Professor W. A. Osborne, of Melbourne, Australia, found that his diurnal curve of temperature maintained its subtropical character for some weeks after he had been living in the temperate zone.

The time of onset of menstruation affords another example; the Hindoo girl begins to menstruate at twelve or thirteen, the English at fourteen to seventeen years of age; an English child taken to India begins this function not at the age appropriate to the native race and the hot climate, but at that indicative of her own.

Birds in captivity, removed from all circumstances that might be supposed to indicate or necessitate journeys, nevertheless become restless at the return of the season for migration.

All activity of organs after the death of the body as a whole (somatic death) are examples of physiological momentum; thus, the possibility of the perfused heart beating, of the liver secreting bile, of the skin glands and hairs surviving, of nerve fibers remaining active, and so on, are all examples of it.

The over production of anti-toxin after the stimulus (toxin) has ceased to operate has been repeatedly quoted by medical writers as a striking example of physiological momentum.

The relations of functional inertia to heredity are intimate and obvious. If functional inertia is a property of cells, and therefore of tissues, organs, systems and organisms, it must also belong to the individuals who compose the race. It is responsible for racial characteristics, it moulds national destinies. Thus, races with much functional inertia, which learn anything new with the utmost difficulty, remain in their racial *status quo* century after century. "Oriental inertia" is, in fact, the term universally used to describe their state of non-receptivity, their holding on in the straight line of their ancestral path.

There is an inertia of character in the family, clan, nation or race. As I wrote in 1908,[3a]

> By environmental stimuli acting through affectability we become educated or trained to be what under other circumstances or in another environment we might never have become; whereas through functional inertia, character is inherited and certain tendencies become innate, and one's individuality unfolds as the underlying ground tone of the life, until we are what we could not in any way whatever help becoming.

[3] R. A. Robertson, "Functional Inertia in Vegetable Organisms," *P. R. S. E.*, 1901–02.

[3a] The functional inertia of living matter. London, Churchill. 1908.

> By internal momentum, the "person," character, individuality, is forced into manifestation in opposition, it may be, to parental objections, the teacher's frown and the disapproval of society generally. It was not affectability in the Bourbons which caused them to be described as learning nothing and forgetting nothing. Functional inertia preserves race peculiarities and guarantees constancy of type through very long periods of time. As Huxley well said, "any admissible hypothesis of progressive modification must be compatible with persistence without progression through indefinite periods." He then proceeds to remark that no order of fishes is known to be extinct. Huxley accepts Haeckel's view that "living matter is urged by two impulses, a centripetal, which tends to preserve and transmit the specific form, and which he identifies with heredity, and a centrifugal which results from the tendency of external conditions to modify the organism and effect its adaptation to themselves. The internal impulse is conservative and tends to the preservation of specific or individual form."

Huxley has described these two tendencies in living matter so well that I must quote from him once more.

> The tendency to reproduce the original stock has, as it were, its limits, and side by side with it there is a tendency to vary in certain directions, as if there were two opposing forces working upon the organic being, one tending to take it in a straight line, the other tending to make it diverge from that straight line, first to the one side and then to the other.

The former tendency I attribute to functional inertia, the latter, of course, to affectability.

Professor J. Arthur Thomson, of Aberdeen, is very emphatic when he writes,[9] "in the light of the fact that frequent as variations are, hereditary constancy or inertia or persistence of specificity is even more marked." He is constrained to use even the very term "inertia," and entirely in my sense, in his valuable and exhaustive monograph on "Inheritance."

PSYCHIC INERTIA AND PSYCHIC MOMENTUM

Inertia and momentum are as clearly demonstrable in the things of the mind as they are in those of the body. Sensations, concepts, emotions, ideas—all mental states—would seem to possess functional inertia and momentum as distinctly as it is possessed by the underlying substance of the nervous system. (I shall not now digress to debate the subject of the causal interdependence of the activities of the nervous system and mental or conscious manifestations, although I may remark that I am a thoroughgoing interactionist.)

Dealing in the first instance with sensations, the argument somewhat as follows. If functional inertia and functional

[4] *Jour. Royal Micros. Soc.*, 1916, p. 448.

momentum are properties of cerebral protoplasm, they must also characterize sensations which have the activity of cerebral protoplasm as their causal physical basis. Professor J. McKeen Cattell long ago put it so well that his words may be quoted. "Inertia is a property of our sense-organs. The molecules of the cells are only set in motion after they have been worked upon by a stimulus of a certain strength for a certain time, and the motion continues after the stimulus ceases." Here Professor Cattell recognizes both psychic inertia and psychic momentum. The latter, indeed, had long ago been described by Hobbes (died 1679) in these words: "Like water troubled, an organ of sense will remain in motion after the removal of the exciting agent." Haller (who died in 1777) wrote, "these" (mutations of cerebral substance) "persist for a long time after the cause which gives rise to them has ceased to operate."

Psychic momentum underlies all those sensory phenomena known as positive after-sensations. The positive after-image is due to this psychic momentum, advantage of which is taken in the kinematograph in which a series of brightly illuminated instantaneous photographs of moving objects produce, by their retinal persistence, the illusion of continuous movements. If each impression vanished instantly, then there would be intermittency or flicker and no fusion of effects, as does occur when the photographs are run through too slowly, giving time for the after-images to fade away. But any given image "outlives" its stimulus in virtue of its functional momentum, and, fusing with the next oncoming image, produces the desired illusion of continuous action and not what it really is, a series of a large number of instantaneous views of moving objects.

On the material side, the positive after-image is due to the functional momentum of the retino-cerebral substance. To its existence is due the fact that a disc half white and half black, rotated in front of us, appears grey; or one half red and half blue, purple; and so on. The fusion of effects is only possible because of persistence of retinal impressions, and these are the results of physiological, psychic momentum.

Similarly, we *feel* contacts, pressures, pains, etc., long after the sources of these sensations have been removed. Who has not still felt his "rubbers" on his feet for some time after he has thrown them off?

Professor Sherrington is constrained to use the very word "inertia" in his article on "Skin, and Common Sensation"[5] thus: "The inertia of the pain apparatus and the inertia of the organs for pain seem particularly great." Writing of pressure applied to the skin, the same author writes, "Pressure applied to the skin makes a sensation which does not subside—the sensation continues."[6] This is psychic functional momentum.

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[5] "Text-Book of Physiology," edited by Schäfer, London and Edinburgh, 1900, Vol. II., pp. 998–999.

Four years after my views on functional inertia had first been put down on paper, I came across (1903) a notable lecture delivered in 1818 by Michael Faraday to a society in London known as the "City Philosophical Society." Speaking of inertia, Faraday says:

> Whatever is in motion is by it retained in motion, and whatever is at rest remains at rest under its sway. It opposes every new influence, strengthens every old one. Is there nothing in the human mind which seems analogous to this power? Is there no spiritual effect comparable to this corporeal one? What are habits? Old prejudices? They seem something like a retention in a certain state due to somewhat more than the active impulses of the moment. . . . The mind seems to remain in the state in which it is, and the words which enunciate parts of our natural law will describe exactly the effect . . . to illustrate at once the force of mental inertia.

Continuing, Faraday writes: "Apathy will represent the inertia of a passive mind, industry that of an active mind." The expression "inertia of the mind" frequently occurs. Enough has been quoted to show that Faraday had clearly before him the reality of mental inertia and mental momentum. The well-marked tendency to do what has been done before, to continue doing what you have just been doing, to yield to the familiar, to habit, is nothing else than the expression of psychic momentum. Every day we have examples of it; some one reads from the newspaper, "thirty or forty" when it was "thirty or fewer" that was written. Oliver Wendell Holmes alleges that not one in ten people can read Judges XV: 16 correctly; the verse is, "And Samson said; with the jawbone of an ass heaps upon heaps, with the jaw of an ass have I slain a thousand men." Nearly every one reads "jawbone" for "jaw" in the second clause.

Mental inertia and mental momentum must be as universal as mental affectability.

Bigotry, superstition and extreme dislike to change are expressions of psychic inertia, while obsession with an "idea" and fanaticism are those of psychic momentum. The riots which occurred in many parts of England on the introduction of machinery, and the violent protests that were raised against the making of railways in the early nineteenth century, are examples of the operation of national functional intertia.

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[6] *Ibid.*, p. 925.

It must not be supposed that the expressions of mental functional inertia are confined to the unreflecting proletariat; practically all the great discoveries in science and medicine have met with opposition not because they were not beneficial, but because they were new.

The discoverers of the circulation of the blood, of vaccination, of anesthetics, of the germ-origin of disease were obstructed and attacked not only by the laity, but by their own professional brethren. Galileo, Harvey, Jenner, Simpson, Pasteur and Lister were worried, ridiculed and persecuted, as all students of the history of discovery know.

Many writers have identified habit with inertia, thus Frank Buckland wrote of the "vis inertiæ of habit" in fish.

Of course it is in religious systems that we find the most perfect examples of psychic inertia and of psychic momentum. As Herbert Spencer put it, "Religious dynasties have extraordinary powers to resist change." National psychic inertia is expressed by national religion. The stolid, fatalistic and unprogressive Oriental is merely expressing his racial, mental inertia.

By psychic inertia instincts, capabilities and incapabilities, predispositions to all manner of activities and non-activities, are carried over into the next generation where they unfold themselves and maintain themselves, not only not in harmony with the environment but often in opposition to it. The environment in matters psychical is chiefly constituted by education and all that that means.

Educability is psychic affectability, ineducability is psychic inertia. It is this that Professor Ribot alludes to when he says that heredity has set a limit to the education of the negro. This is only another way of saying that it is the misfortune and not the fault of the negro, as it is with all who have inherited ineducable disabilities.

This pessimism has been extended by Monsieur Guyau when he says that education is powerless to modify to any great extent the radical temperament or character of the individual. According to this view, the criminal as well as the poet *nascitur non fit,* the child's whole moral destiny is contained within it while as yet unborn.

We may take the hypnotic trance as a good example of psychic inertia, in that phase of it in which profound anesthesias and analgesias are developed so remarkably and so mysteriously.

THE ORIGIN OR GENESIS OF FUNCTIONAL INERTIA

All the properties or powers of living matter are not possessed exclusively by living matter. Certain properties or powers are characteristic of living matter and are not possessed by matter that is not living. Thus, the powers of reproduction, digestion and assimilation, are characteristic of living matter and are not shared by matter that has not ever lived. Crystals, for instance, do not reproduce themselves, nor can they incorporate material dissimilar from their own substance; but it is just these things that living beings can do. The "growth" of a crystal has nothing in common with the "growth" of an organism except the name.

Non-living matter is, however, affectable; if by affectability we mean the power of responding to a stimulus. Thus, gunpowder is highly affectable towards a spark, in that it will respond to such by an explosion, that is, it will convert violently its potential chemical energy into the kinetic forms of heat, light, sound and molecular disruption. Gunpowder, therefore, has affectability towards sparks as "stimuli." But gunpowder will not be exploded by concussion; it has, therefore, inertia towards concussion as a stimulus; if it is the "function" of gunpowder to explode, then it has "functional" inertia towards concussion, but high affectability towards sparks.

Affectability and functional inertia are possessed by such kinds of non-living matter as are designed to transform energy that is, to perform functions. Another example may be taken in the case of cordite; if it is the function of cordite to explode, then it has affectability towards concussion which causes it to explode, but it presents functional inertia towards sparks, which merely make it burn, but not explode.

It is, therefore, highly probable that just as the affectability of living matter is foreshadowed by that of non-living matter, so physiological inertia is foreshadowed by the inertia of non-living molecules.

As a pure speculation, protoplasmic inertia may be assumed to have been evolved from the molecular inertia of non-living matter and in particular from that of the carbon atom. Professor J. C. Bose, of Calcutta, has contrived to demonstrate in non-living matter such phenomena as latent period, post-stimulant effects, and fatigue, on the one hand, as well as staircase responses, summation of effects, diphasic electrical variation, the results of varying temperatures and of different poisons, on the other. Such results are due to the existence of molecular inertia and of affectability respectively in the non-living mechanisms with which he worked.

Affectability and functional inertia are, therefore, not differentiae of living matter in the sense that the powers of reproduction, assimilation and excretion are. Only living matter can grow (metabolise) and reproduce itself, but both non-living matter and living matter can, under certain circumstances, respond to a stimulus, and under others, refuse or fail to do so.

Molar and molecular inertia are universal properties in that they are possessed by all forms of matter and by all mechanisms whether living or non-living which have the power of transforming energy.

Functional or physiological inertia is a property of all living matter (bioplasm) not merely by way of analogy with the inertia of non-living molecules, but because in its genesis such a property must have been derived from the fundamental property of non-living matter.